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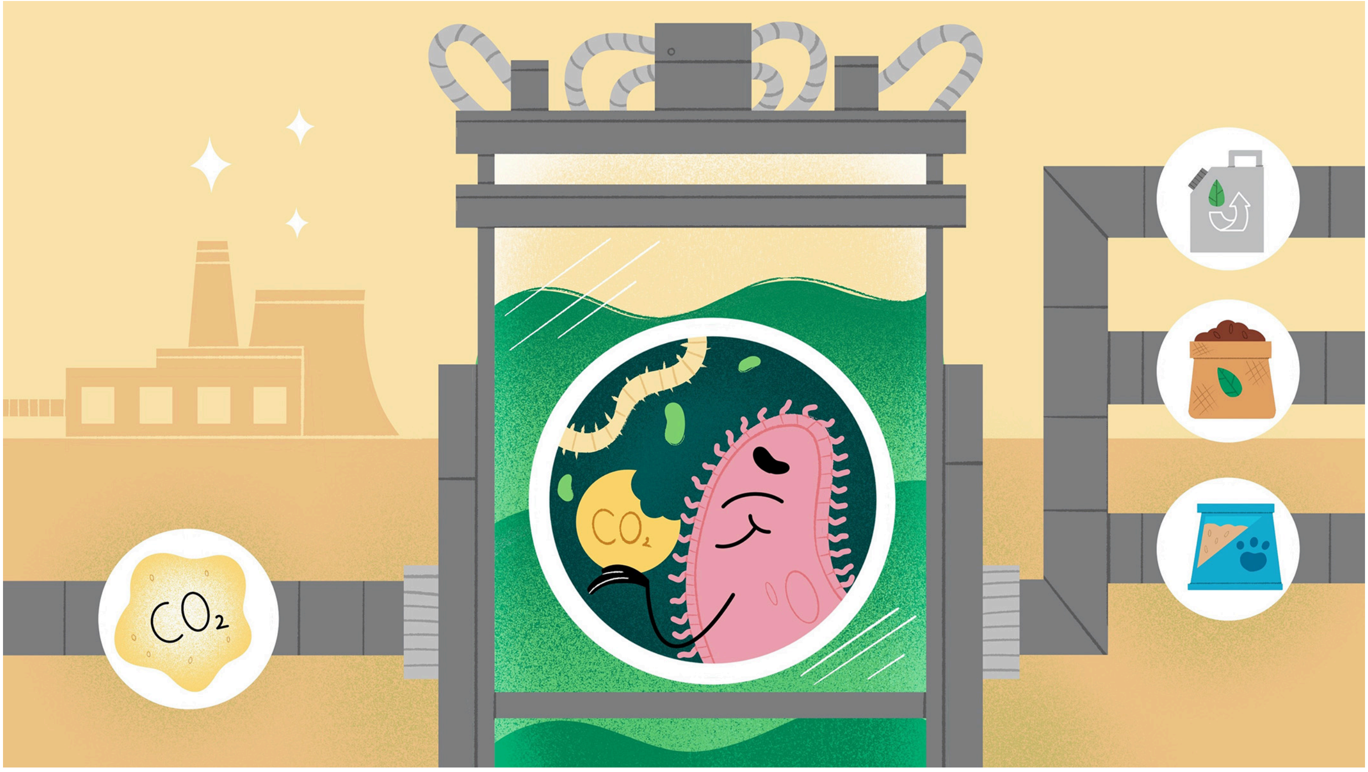

TURNING POLLUTION INTO SOLUTIONS USING MICROBES

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Microbial carbon capture is a new technology that uses tiny living organisms, like bacteria and microalgae, to absorb carbon dioxide (CO_2) and turn it into useful products. These microbes can create products like fuel, fertilizers, or animal feed, helping to fight climate change while also supporting industries including farming and energy. Scientists can enhance these microbes by altering their genes, to make them even better at capturing CO_2 and producing valuable materials. This technology is already being tested in factories, farms, and other industries. For example, devices called photobioreactors can use sunlight to turn CO_2 released by factories into fuels, while other systems use waste materials like food waste to power microbes in areas without sunlight. Despite some ongoing challenges, microbial carbon capture has the potential to reduce

greenhouse gas emissions, create valuable products, and contribute to a more sustainable future.

THE WORLD NEEDS A NEW WAY TO REDUCE POLLUTION

Have you ever seen smoke coming out of factory chimneys and wondered how it affects the environment? Many industries release waste gases including carbon dioxide (CO_2), one of the biggest causes of climate change. Greenhouse gases like CO_2 trap heat in Earth's atmosphere, causing temperatures to rise and leading to extreme weather events, rising sea levels, and harm to ecosystems. Human activities, such as burning fossil fuels for energy and industrial processes, are responsible for much of the excess CO_2 being released.

While some factories try to control emissions by using filters to trap solid particles or scrubbers to remove certain chemicals, these methods are often expensive and use a lot of energy, and sometimes they are only partially effective. In many cases, CO_2 is simply released into the air. To encourage companies to reduce emissions, some governments charge fines for releasing too much CO_2. However, these fines do not always work as intended. Many factories lack the equipment or technology needed to significantly lower their emissions, so they end up paying the fines rather than solving the problem.

To effectively fight climate change, we need to find a better way to reduce the amount of CO_2 being released into the atmosphere. What if we could capture CO_2 directly from industrial exhaust systems before it enters the air, turning it into useful products instead of polluting the environment?

EMERGING TECHNOLOGY: MICROBIAL CARBON CAPTURE

Microbial carbon capture uses tiny living organisms, such as bacteria and **microalgae**, to absorb CO_2 from the air or from factory exhaust and turn it into useful products like fuel, fertilizer, or even protein-rich animal feed (Figure 1). These microorganisms naturally capture carbon, but scientists enhance their abilities through **genetic engineering** and other methods to fine-tune how they capture and use carbon. By changing the microbes' DNA, researchers can make them even better at absorbing CO_2 and transforming it into valuable substances.

MICROBIAL CARBON CAPTURE

A technology that uses tiny living things, like bacteria and microalgae, to absorb CO_2 and turn it into useful products.

MICROALGAE

Tiny plants that live in water and use sunlight and CO_2 to grow. They are important for microbial carbon capture and can create things like biofuels or fertilizers.

GENETIC ENGINEERING

A way scientists change the DNA of living things, like microbes, to give them new abilities, such as absorbing more CO_2 or making useful products.

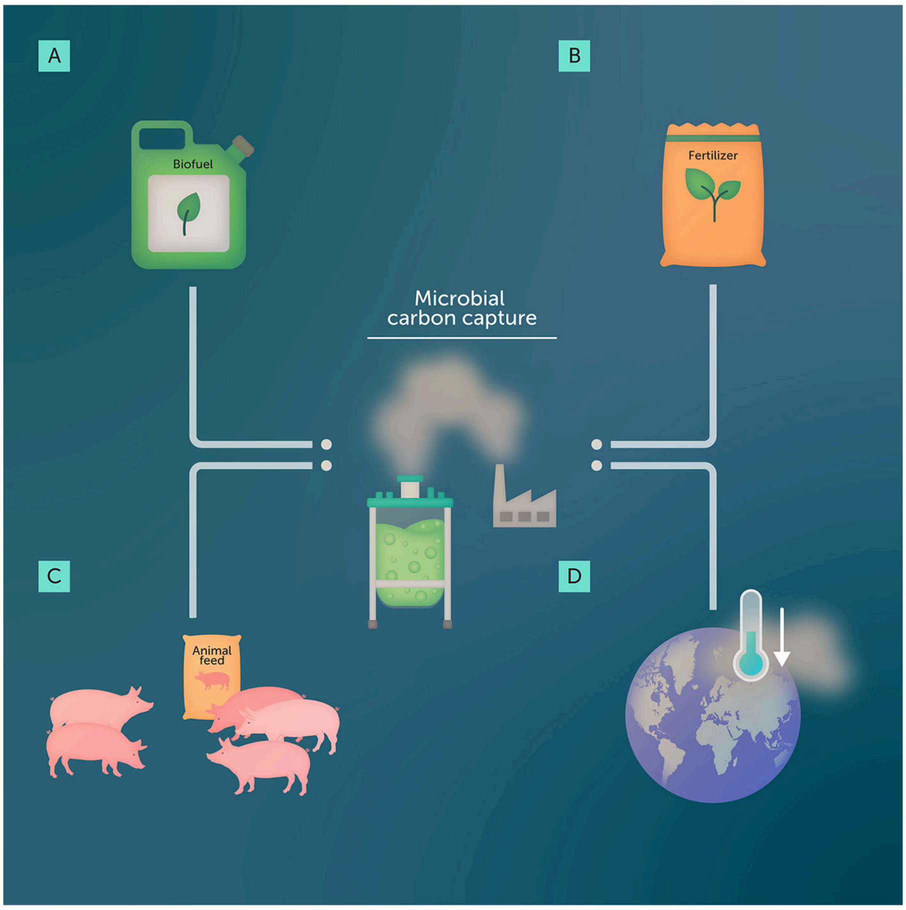

Figure 1

Figure 1

Microbial carbon capture involves growing tiny living organisms that can turn CO_2 from factories or power plants into useful products, including: **(A)** biodiesel, a renewable fuel that could replace fossil fuels like gasoline or diesel for powering vehicles or machinery; **(B)** environmentally friendly fertilizers for farm crops; and **(C)** protein-rich feeds for farm animals. **(D)** Overall, microbial carbon capture could reduce greenhouse gas emissions, limiting global warming and contributing to the health of our planet.

There are two main types of microbial carbon capture systems: **photobioreactors** and **chemical energy systems**. Photobioreactors use tiny photosynthetic organisms like cyanobacteria or microalgae, which absorb CO_2 and sunlight to create energy and produce new, useful compounds. Photobioreactors and some chemical energy systems work by bubbling CO_2-containing gases through a liquid where the microbes grow. However, instead of relying on sunlight like photobioreactors, chemical energy systems use microbes that get their energy from chemicals like hydrogen or organic waste, such as food scraps or farming byproducts [1]. These microbes absorb CO_2 and use the energy to produce valuable products. Because chemical energy systems do not need sunlight, they can be used in places where natural light is limited.

PHOTOBIOREACTORS

Systems that grow photosynthetic organisms, like microalgae, by using sunlight and CO_2 to create energy and useful compounds.

CHEMICAL ENERGY SYSTEMS

Microbial carbon capture systems that use chemicals, like hydrogen or organic waste (e.g., food scraps or farming byproducts), to power microbes instead of sunlight.

TECH TO THE RESCUE

Microbial carbon capture is already being tested to help industries that release large amounts of CO_2, like factories and power plants. Microbial carbon capture systems could be installed near the ends of the pipes or chimneys that release CO_2, where gases are the coolest.

BIODIESEL

A renewable fuel made from plants, algae, or microbes that can replace traditional fuels like gasoline or diesel.

Photobioreactors placed alongside these exhaust systems can use CO_2 and sunlight to produce **biodiesel**, a renewable fuel that could replace fossil fuels like gasoline or diesel for powering vehicles or machinery.

Farming could also benefit from microbial carbon capture. The process of making nitrogen-containing fertilizers, which help crops grow, uses a lot of energy and releases large amounts of CO_2. Engineered microbes that can change CO_2 into nitrogen-rich compounds could provide a greener alternative, making fertilizers directly from waste gases. Microbial carbon capture could also be used to produce healthy food for farm animals. By feeding microbes CO_2 and other nutrients, those microbes can grow into a protein-rich substance that could be fed to farm animals instead of traditional feed like soybeans, which require a lot of land, water, and fertilizer to grow (see more about alternative animal feeds here). Using microbes instead of crops for animal feed helps save natural resources and reduces the environmental impact of farming.

One of the most exciting things about microbial carbon capture is how flexible it is. Scientists can adjust the microbes or the systems to create specific products for different industries. For example, a company working on renewable energy might use the system to make biofuels (like biodiesel), while a construction company could produce materials like carbon-based additives for concrete. By turning emissions into useful products, these systems can help companies save money, avoid fines for releasing too much CO_2, and even create new ways to earn income.

BIG CHALLENGES, BIGGER OPPORTUNITIES

While microbial carbon capture is promising, there are still challenges to overcome before it can be widely used. One big challenge is that many microorganisms work best in cooler conditions, making it hard for them to capture CO_2 from hot exhaust gases like those from power plants or factories. To solve this, researchers are exploring ways to make the microbes more heat resistant or to cool the gases before they reach the microbes, but these solutions add cost and complexity [2].

Another challenge is scalability, or how to make these systems big enough to work in large factories and power plants. Right now, most microbial carbon capture systems are still in the testing phase. Some are being studied in labs, while others are being tested in small factories or test projects. Scientists are working on ways to make these systems larger and more efficient so they can handle the huge amounts of CO_2 released by industries.

Cost is another issue [3]. Building and maintaining microbial carbon capture systems is expensive, especially compared to traditional methods of managing emissions like planting trees or using filters to capture pollutants. However, the valuable products these systems create—like biofuels, fertilizers, or animal feed—could help balance out some of these costs, making the systems more appealing to companies.

Location is also a challenge. Photobioreactors need lots of sunlight to work well, so they are best suited to sunny areas. Similarly, chemical energy systems need access to renewable energy (like solar, wind, or hydropower), which is not yet available everywhere. Expanding access to clean energy will be key to using these systems in more places.

If these hurdles can be overcome, microbial carbon capture could help reduce greenhouse gas emissions, create valuable products, and support industries from agriculture to construction—helping to fight climate change and build to a more sustainable future.

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YOUNG REVIEWERS

TRILOK, AGE: 12

Trilok is a whirlwind of energy, curiosity, and just the right amount of mischief! With a mind that zips through physics like a football on a perfect pass, he is always questioning, tinkering, and dreaming up the next big thing in automobile technology. Intelligent and creative, he is the kind of student who makes learning an adventure—whether it is cracking a tricky concept or cracking a joke! A lover of speed, science, and a little fun, Trilok keeps life anything but boring!

VANSHIKA, AGE: 14

Hai, I am Vanshika. I am a 14-year-old girl with interests in playing the flute and dancing. Apart from this, I am also a good orator and a fairly avid reader. I usually opt for psychology and philosophy books as they improve my understanding of life. I am very interested in archaeology, architecture, and different traditions, where I believe there are numerous scientific concepts yet to be discovered. As for sports, I am good at basketball and chess.

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Sang Yup Lee is a scientist who leads research at the Korea Advanced Institute of Science and Technology (KAIST). He studies how to use tiny living things, like bacteria, to make useful products such as fuels and materials. His work helps create eco-friendly alternatives to traditional chemical processes. Dr. Lee has received many awards for his contributions to science and serves on advisory councils to share his expertise.

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